Characterizing Building Blocks

Metrics for informed design

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The Problem

- Develop useful system characterization techniques to inform application development.
- Use portable techniques.
- Explore issues of balance.
- Squeeze more performance out of the technology we've got.

An Apology:

- YOU already know all this stuff
- Your colleagues may not
- Use these slides as material for *their* enlightenment.

The Counter Argument

- But if I develop the application with a particular machine model in mind, it will become machine specific!

- Is it better to develop a code that runs equally poorly on *all* machines?
- Pick a model/architecture/vendor that has a point-of-view that aligns with your application domain.

The Computational Model

- For a large set of interesting problems

$$T_{sol} = T_{arith}/N + T_{mem}/N + T_{IO} + f(N)T_{comm}$$

or

$$T_{sol} = MAX(T_{arith}/N, T_{mem}/N, T_{IO}, f(N)T_{comm})$$

- We know how to characterize T_{arith} (DGEMM is OK)
- Stream Triad is a good indicator for T_{mem}
- How to characterize T_{comm}?

The Platform

- 5832 Low Power MIPS Processors
- 972 Six-way SMP nodes
- High Bandwidth Inter-node Fabric
- 108 PCI Express IO ports
- 72 GB Ethernet
- 15KW to 20KW

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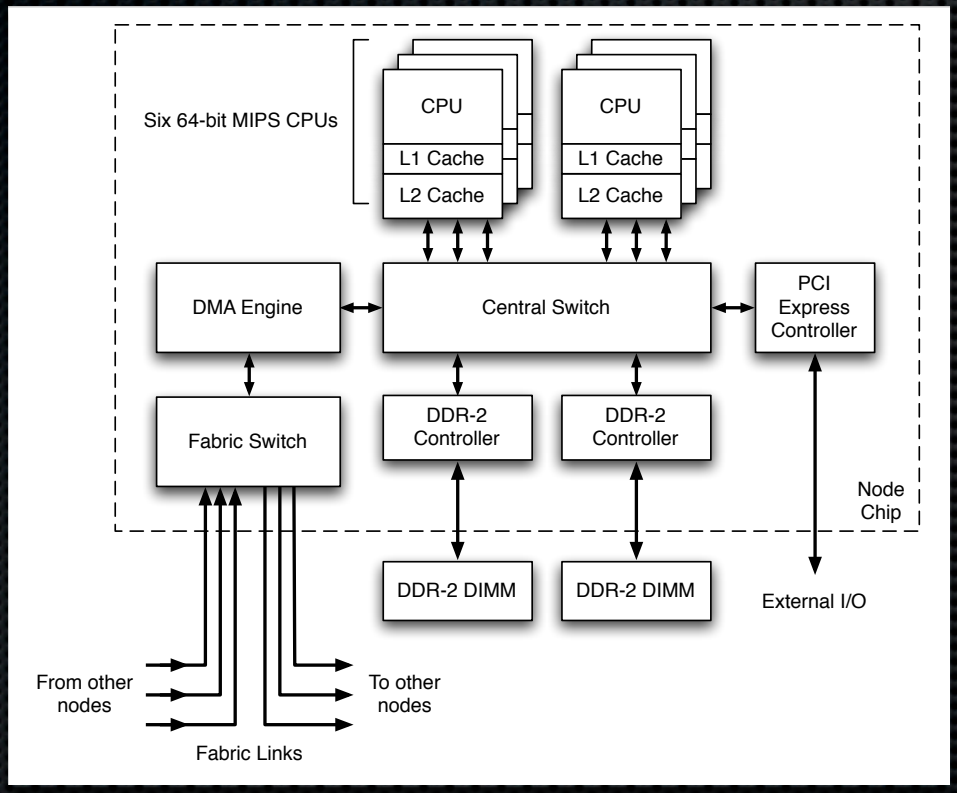
The SiCortex Node Chip



Six way Linux SMP with 2 DDR ports, PCI Express, Message controller, and fabric switch

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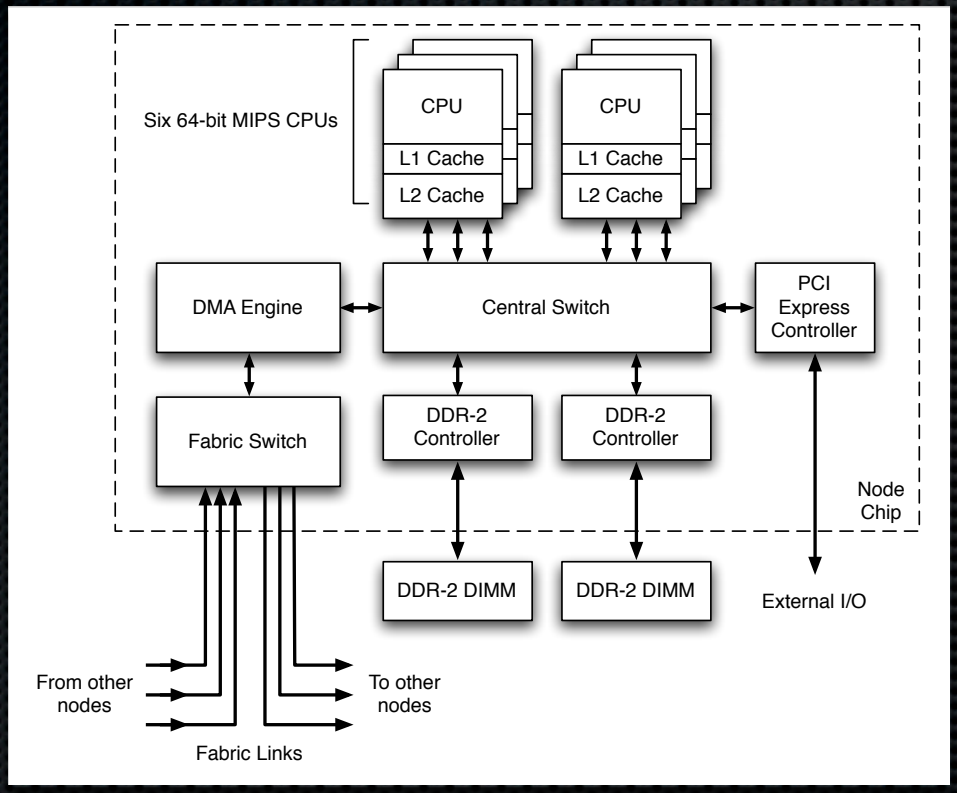

x 972

SC5832: 972 SiCortex nodes connected in a degree 3 Kautz Graph

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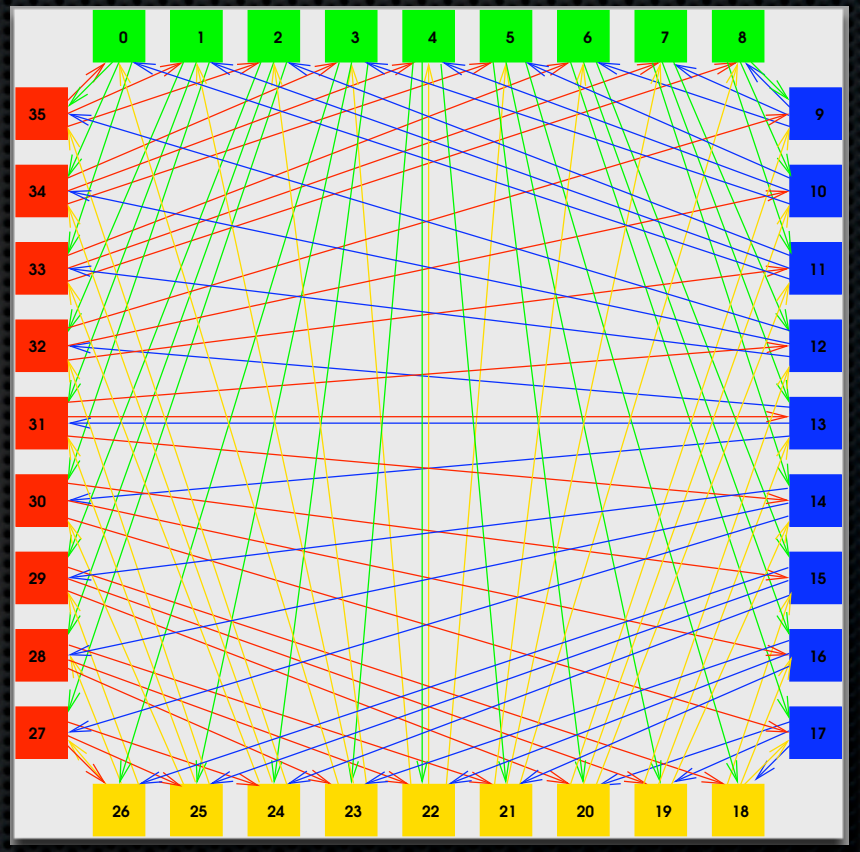
The Kautz Graph

- Logarithmic diameter
- Reconfigure around failures
- Very fast collectives
- 972 nodes: diameter 6



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The Computational Model

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- How to characterize T_{comm}?

MicroBenchmarks and Kernels

- MPI Latency - 1.4 µsec
- MPI BW - 1.5 GB/s
- HPC Challenge work underway
- SC5832, on 5772 cpus:
  - DGEMM 72%
  - HPL 3.6 TF (83% of DGEMM)
  - PTRANS 210 GB/s
  - STREAM 345 MB/s (1.9 TB/s aggregate)
  - FFT 174 GF
  - RandomRing 4 usec, 50 MB/s
  - RandomAccess 0.74 GUPS (5.5 optimized)

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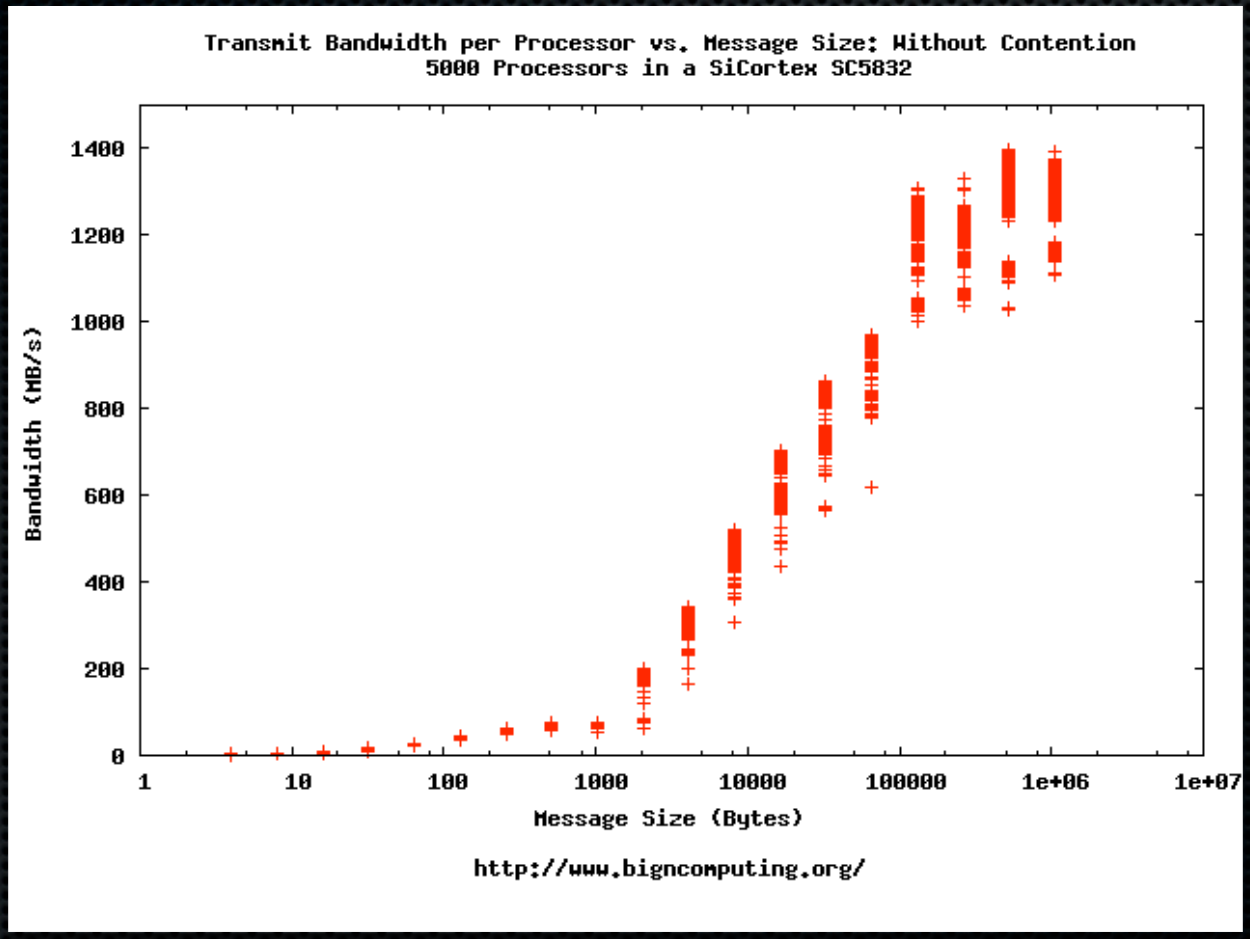
Zero contention message bandwidth?



Interesting relationship between message size and bandwidth

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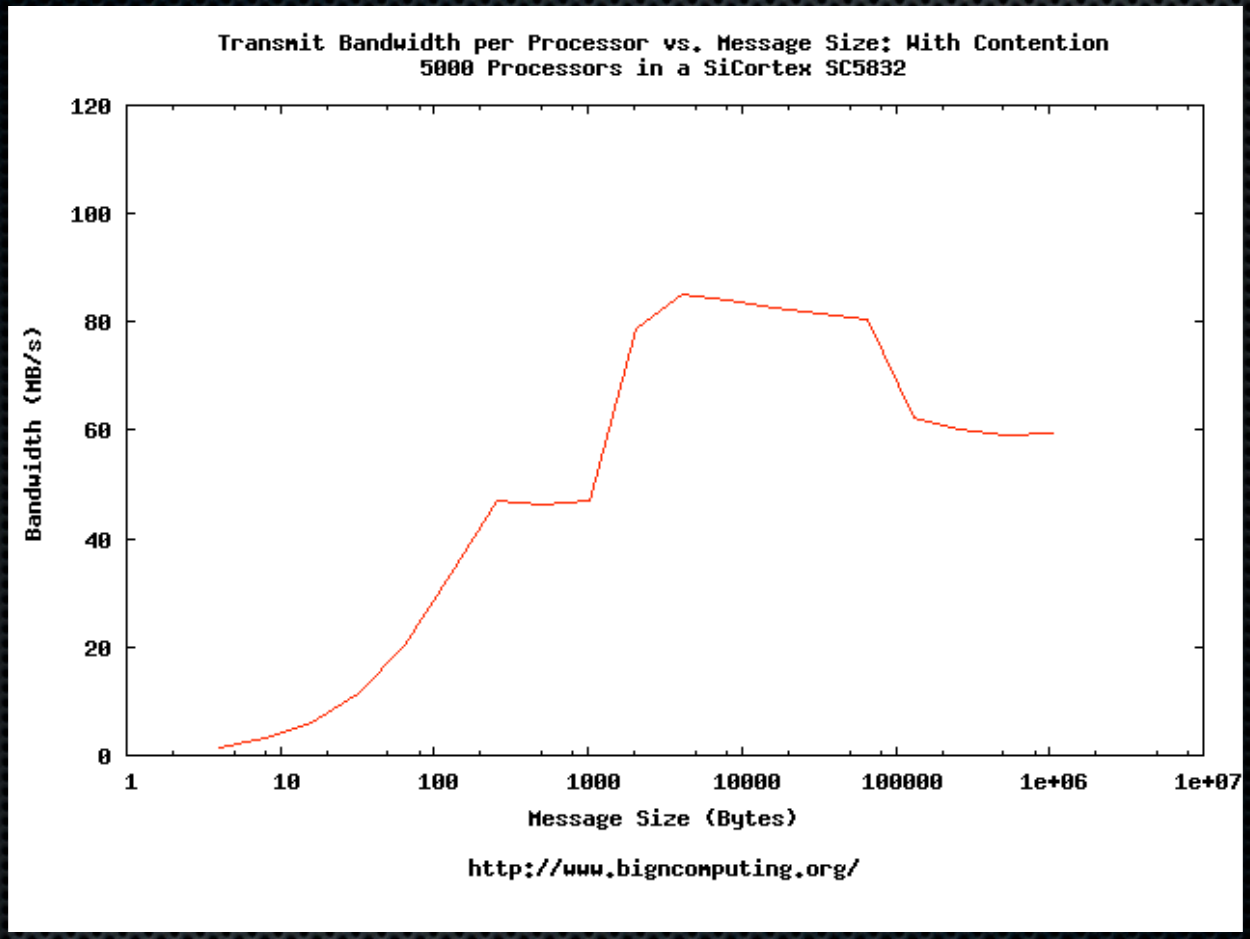
Communication in “real world” conditions



Contention matters. (For more, see Abhinav Bhatele’s work at http://charm.cs.uiuc.edu/ .)

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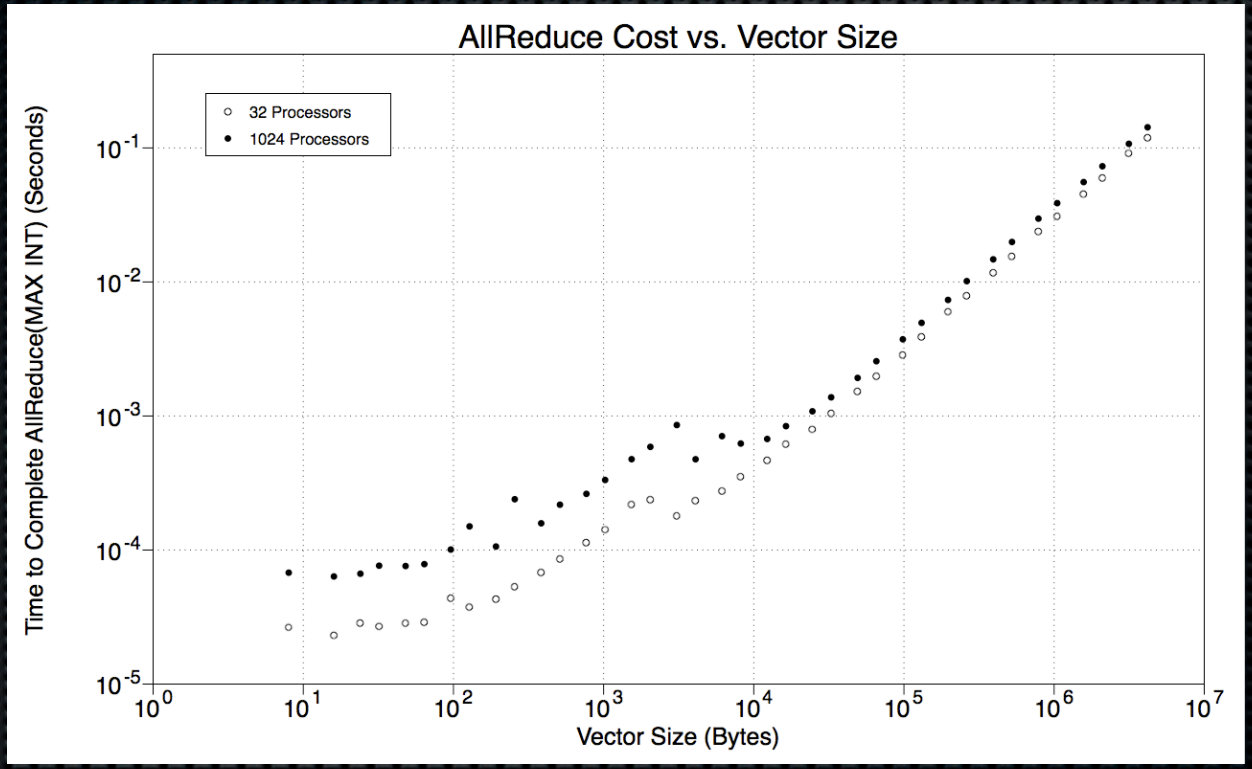
What about Collectives?



Dependence on vector size is predictable.

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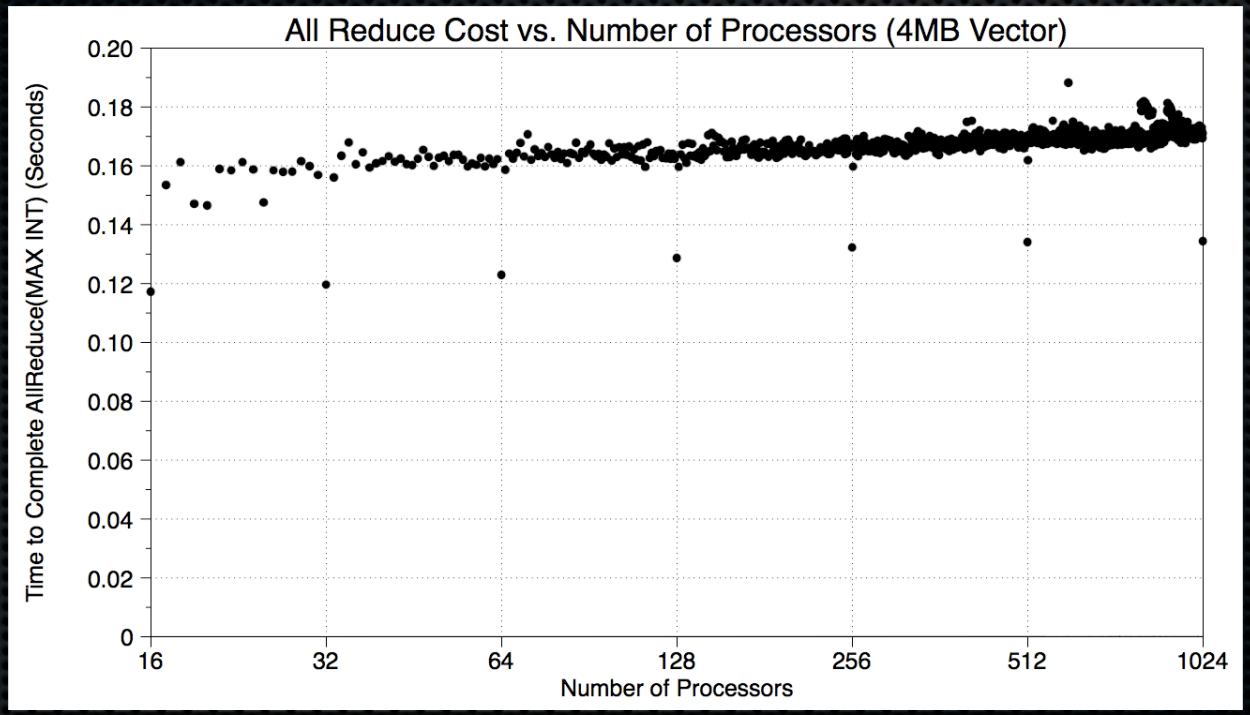
Collective Cost vs. Number of Processes



Note the optima.

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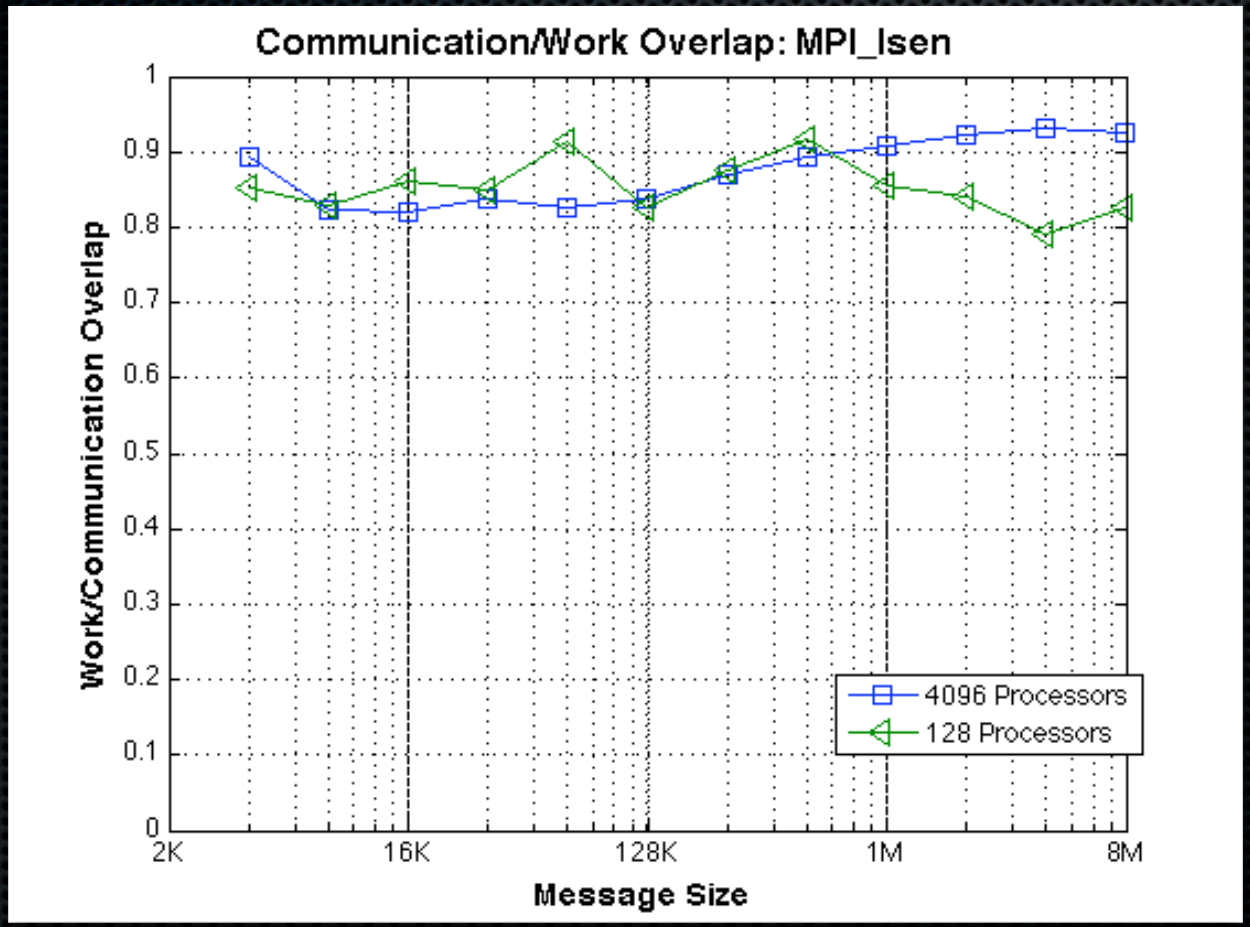
How much can we overlap “work” with “comm”?



Can we mitigate T_{comm}?

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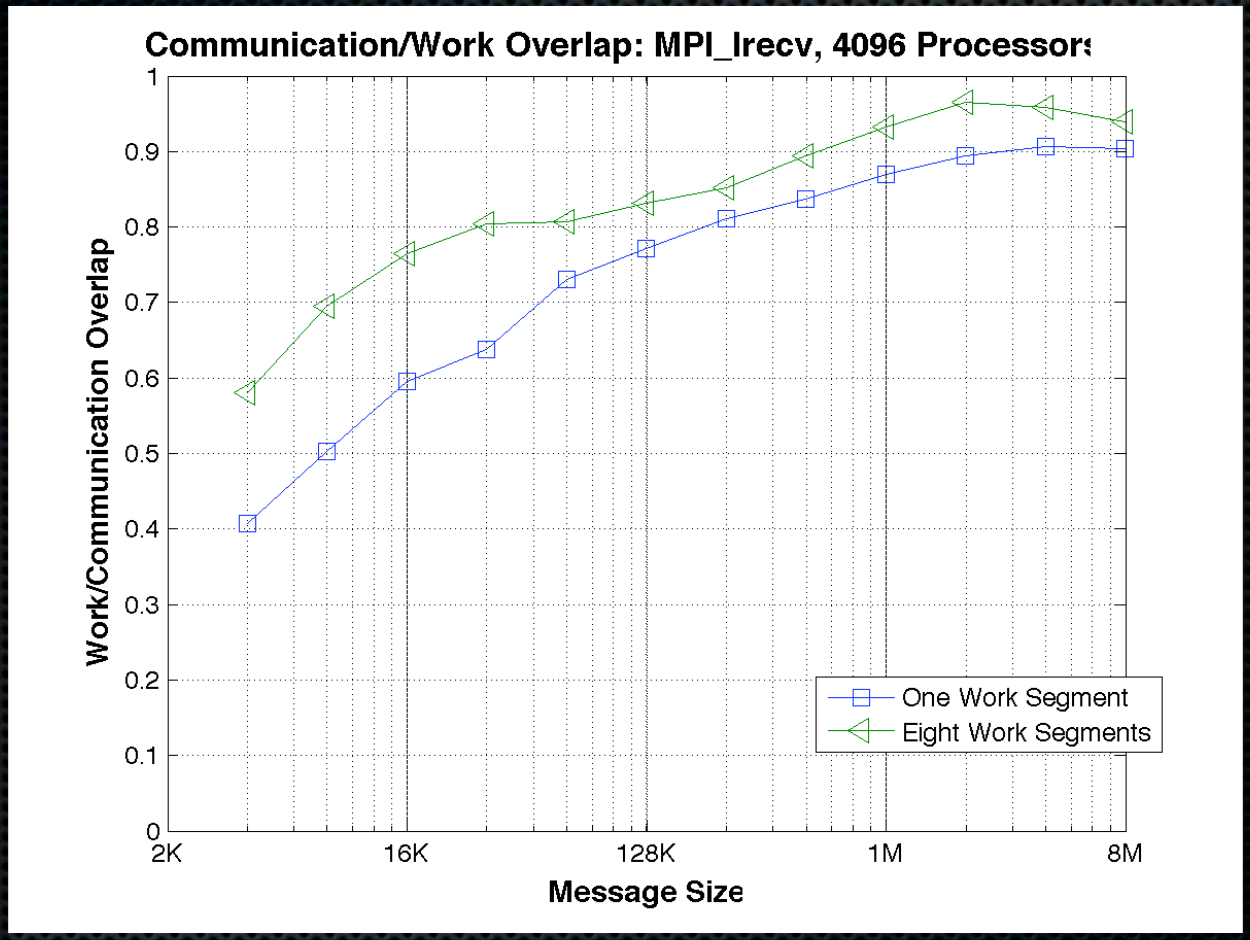
How much Overlap with Receive Ops?



It may pay to fiddle the algorithm a bit...

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Key MPI Performance Features

- Sweet spot is for messages from 2KB to 64KB.
- Best high-contention BW is around 80MB/s.
- Simple collectives cost
  - < 200nS per byte for 1K to 10K.
  - < 60nS per byte for 10K and up.
- Good send/recv overlap opportunities for messages > 16kB

Some Examples

- TeraByte Sort
- Three-Dimensional FFT

TeraByte Sort

- Sort 10 billion 100 byte records (10 byte key).
- Leave out the IO (this isn't quite the Indy TeraSort benchmark)
- Use 5600 processors

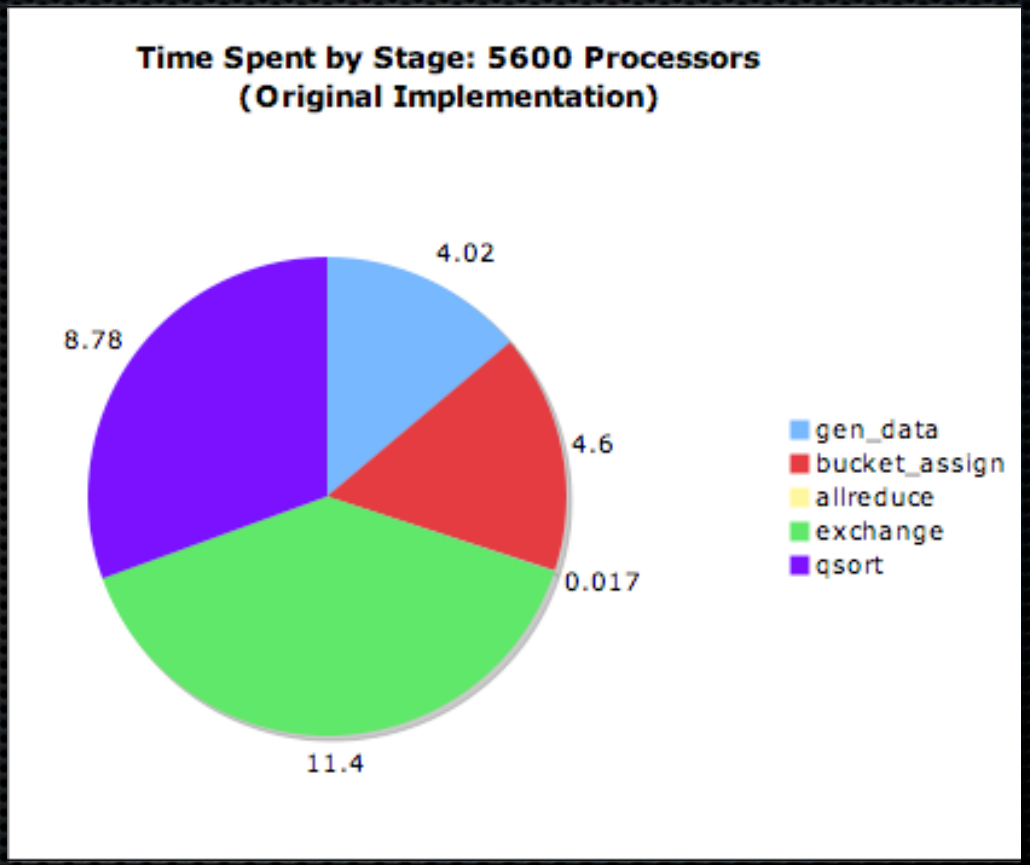
- Key T_{comm} attributes:
  - Time to exchange all 1TB is about 4 sec +/-
  - Time to copy each processor's sublist is about 1 sec +/-
  - Global AllReduce for a 256KB vector is O(10mS)

Problem Approach

- Use Bucket/Radix Sort to partition list among workers
  - bucket assignment (copy sublist and re-arrange) 1sec+
  - global All Reduce: 0 sec +
  - complete exhange of all records 4 sec+
  - parallel sort of ~2M records 4 sec+ (42M record accesses that cause a cache miss... T_{mem} is often proportional to main memory access time.)

From first implementation...

- Exchange seems a little long.
- QSort is way too long.
- Bucket assign seems long.
- Use our initial model to guide the tuning effort.



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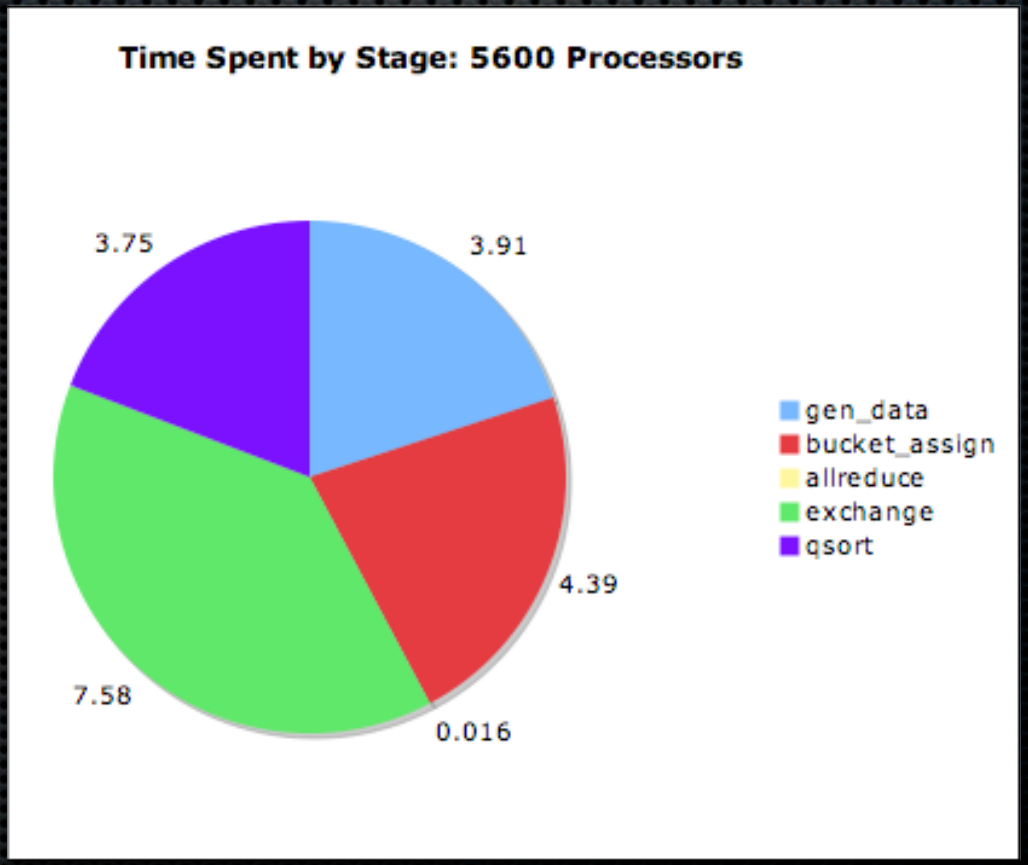
Tuning....

- Improved QSort to the model target
- Bucket assignment is still very slow
- Exchange is still a little slow (by almost 2x!)
- We can do better...



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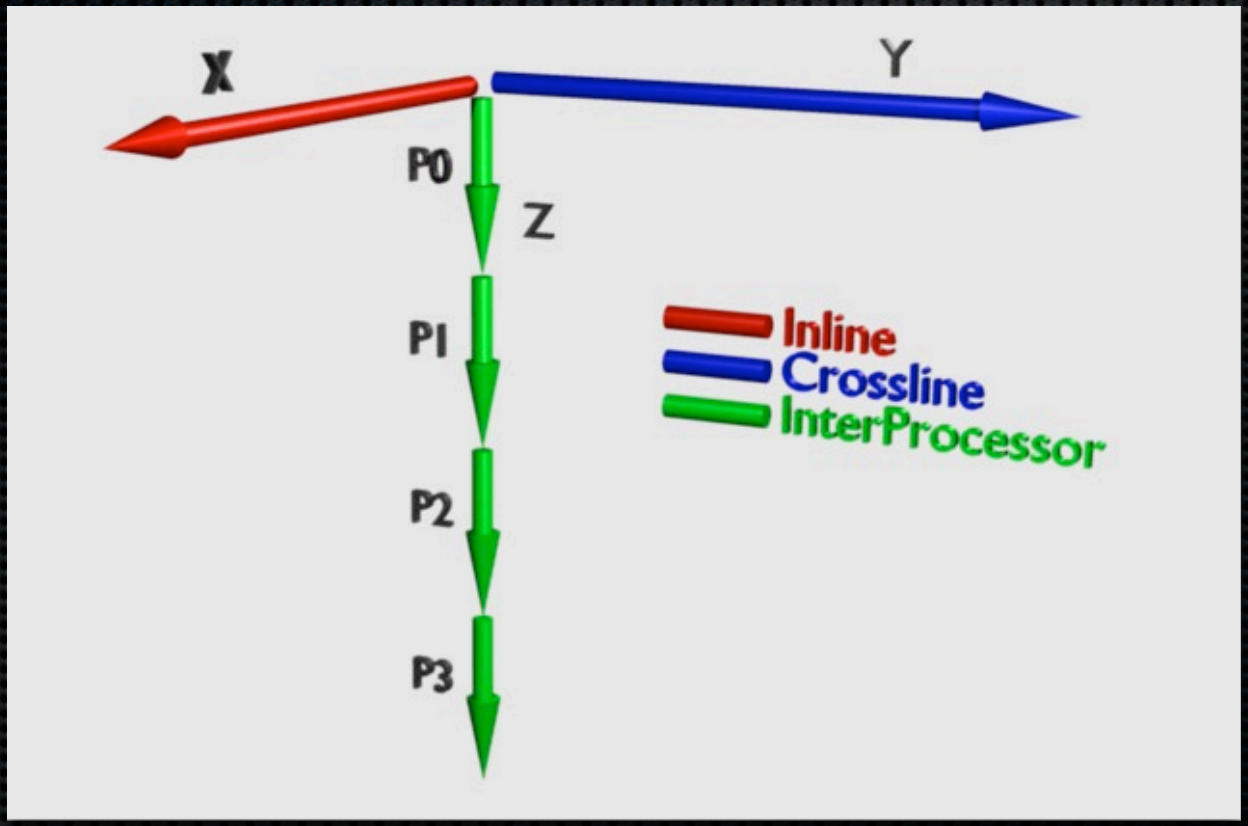
Three-Dimensional FFT

- 3D FFT of 1 billion point volume
- Use PFAFFT (prime factor analysis)
  - complex-complex single precision
  - 1040 x 1040 x 1040
- Two target platforms:
  - SC072 -- 72 processors
  - SC1458 -- 1458 processors

Problem Approach

- We know T_{arith} for 1040 point FFT ~ 200uS
- 1040 = 5 * 13 * 16: so
  - SC072: use 65 processors
  - SC1458: use 1040 processors
- Concentrate on the 65 processor implementation
  - Each proc owns 16 planes of 1040 x 1040
  - Each proc performs 16 2D FFT ops (about 6 sec)
  - Global 3D transpose: (128MB per proc, about 1.5 sec)
  - Each proc performs 16 *1040 1D FFT ops (about 3 sec)

Step 1: FFT in X direction



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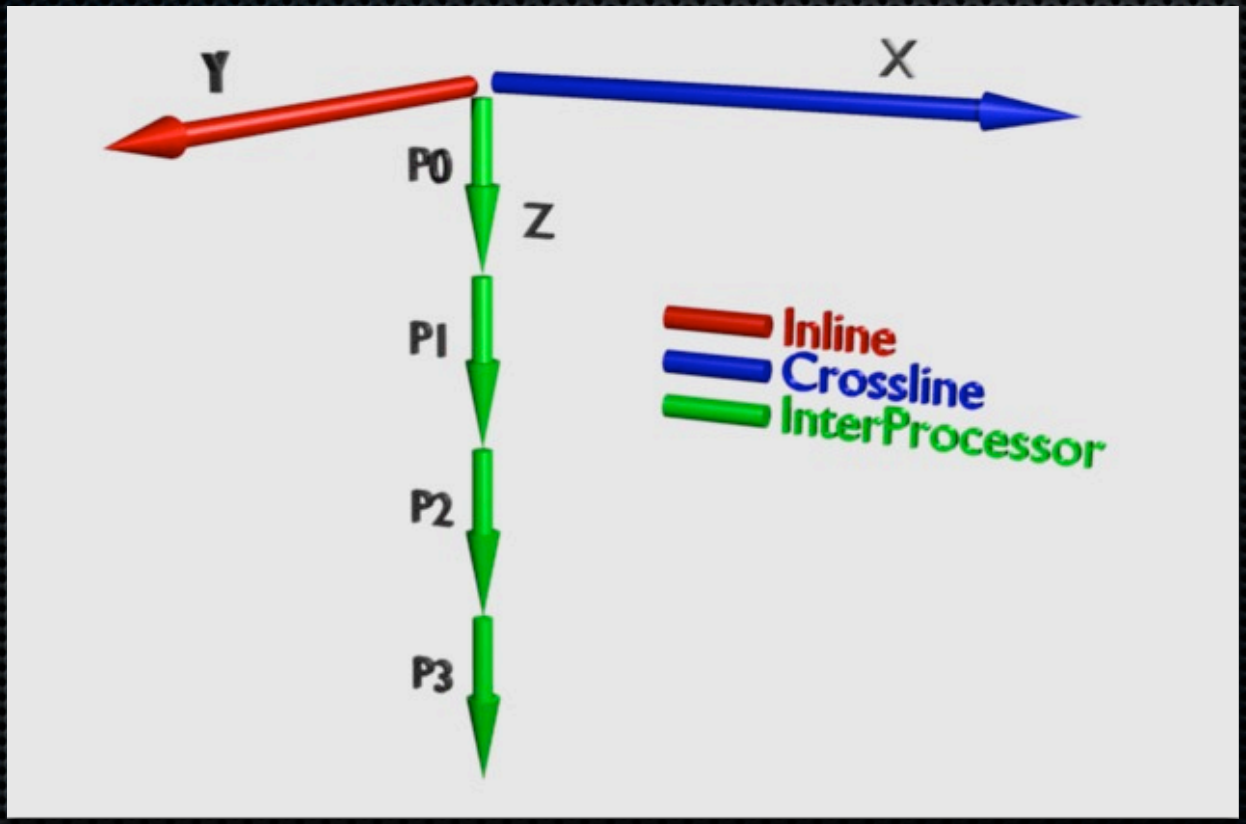
Step 2: FFT in Y direction



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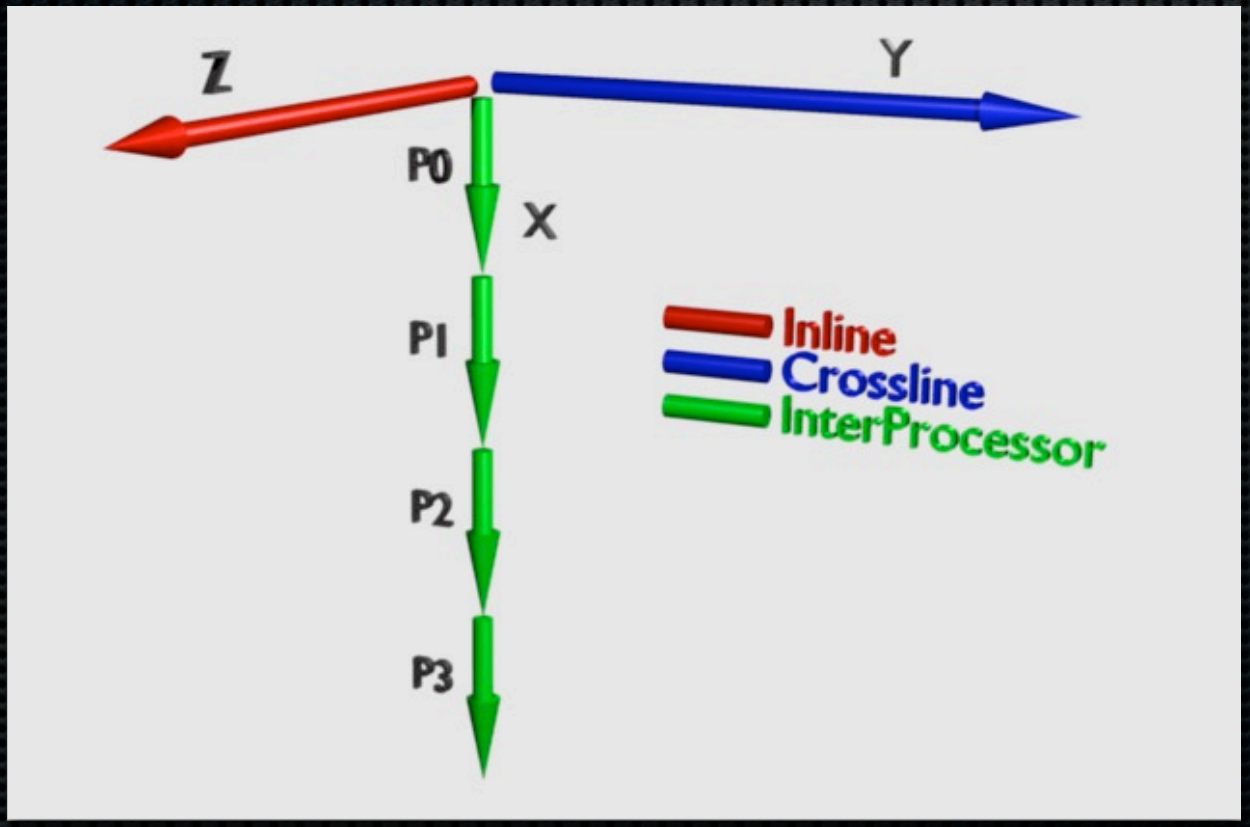
Step 3: FFT in Z direction



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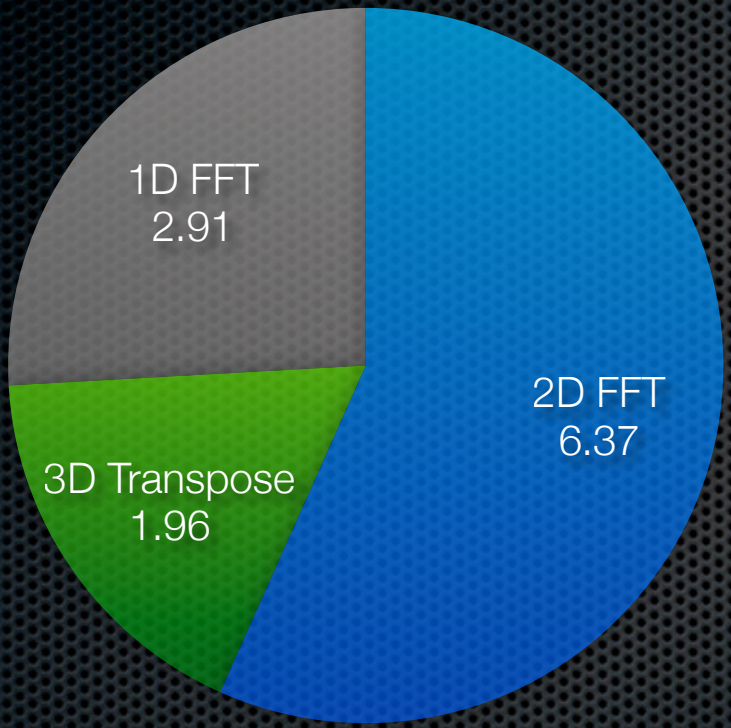
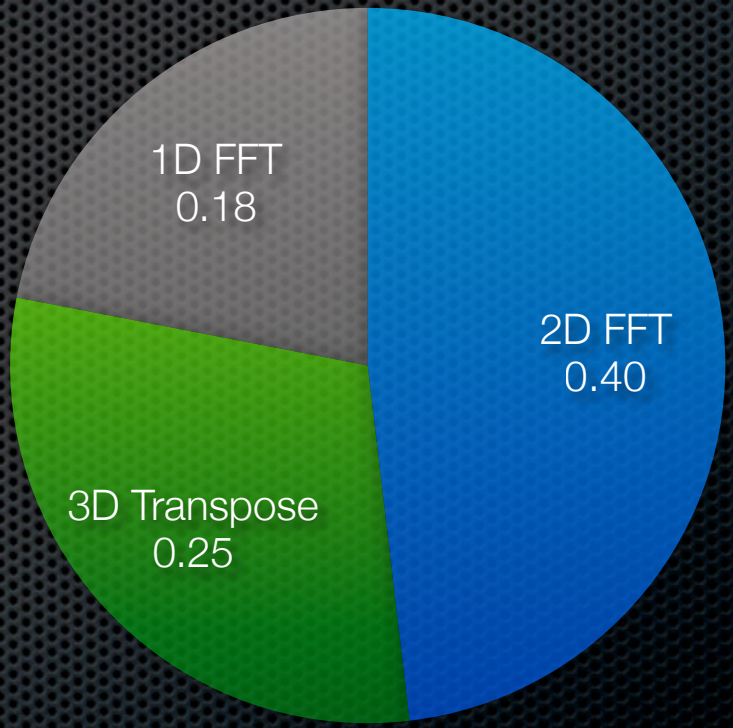
Results!

65 Processor 3D FFT



1040 Processor 3D FFT



Prediction was pretty much on target. (But the transpose is still a little slow...)

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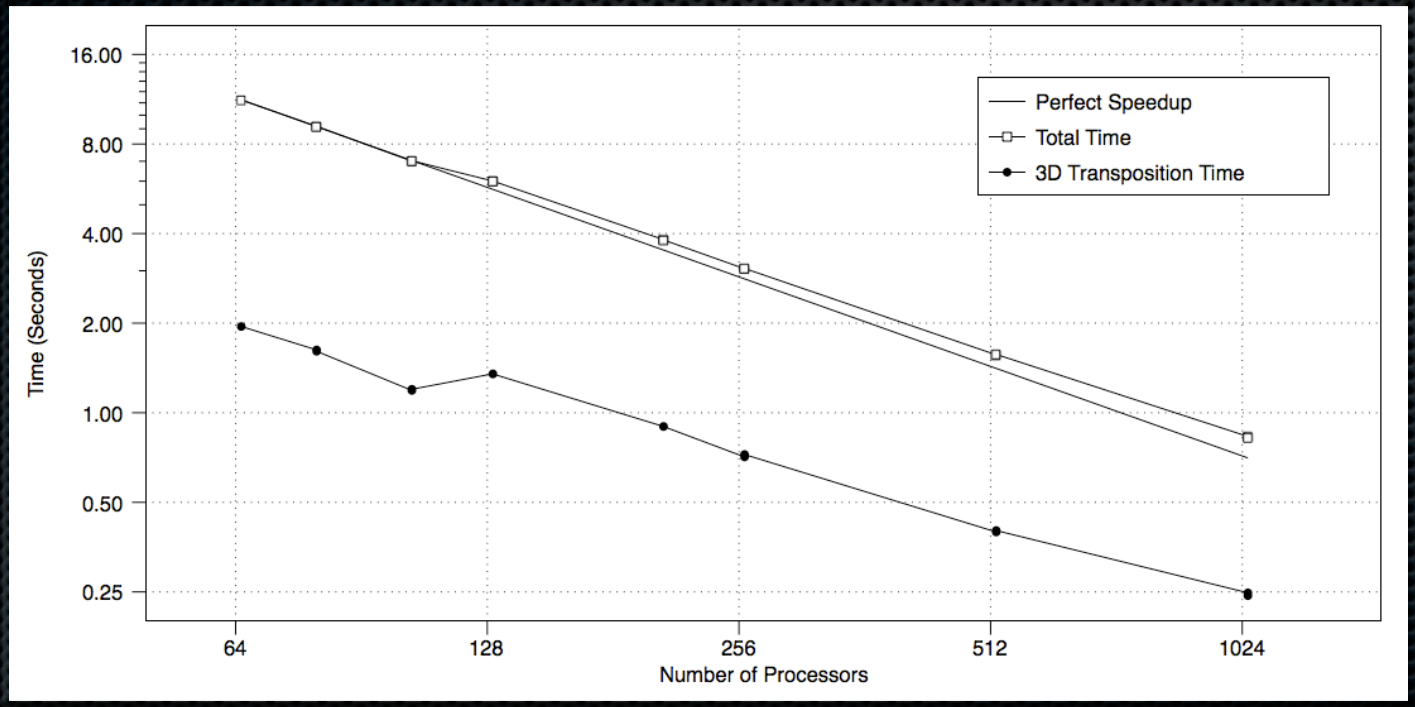
Scaling on the SC1458



The transpose bump is interesting...

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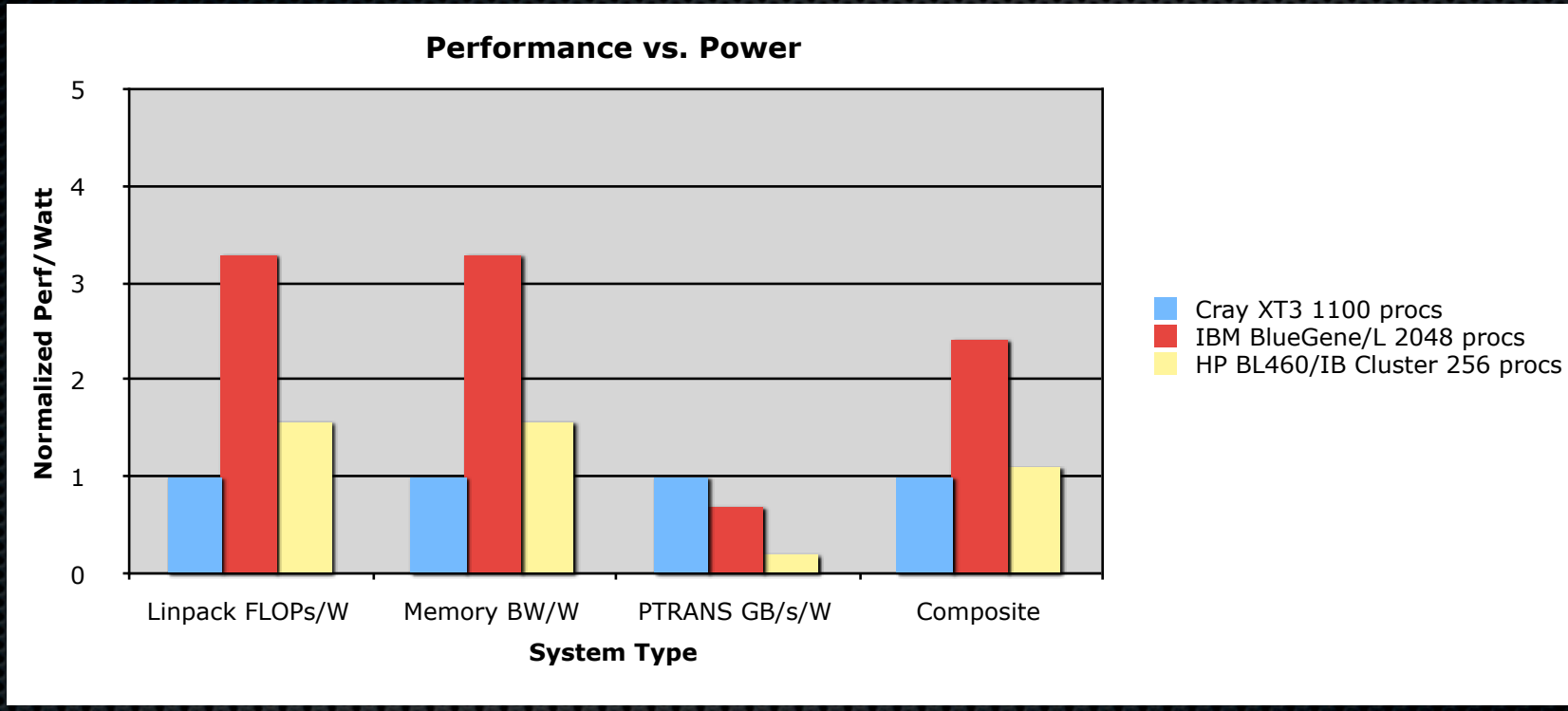
If there is time for a Rant:

- Our approach to “Green” characterization so far is...:
  - Too often vendors “paint it green”
  - Closer in shade to a pale chartruese
- If performance is N-dimensional, we should measure “Green-ness” that way.
  - Linpack/Watt assumes that all computers spend all their time multiplying large matrices.
  - We should recognize the tuple.

A Green Evaluation Model

- Tuple: <DGEMM, STREAM-TRIAD, G-PTRANS> to cover T_{arith}, T_{mem}, T_{comm}
- Normalize wrt a generally respected model:
  - Cray XT3 - well balanced, not quirky
- Measure Tuple, divide by power input (+ cooling cost?), normalize to XT3

A Comparison



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Wrap-up

- Simple metrics can successfully guide *small* development efforts.
  - can this work in the large?
- T_{comm} is properly considered as a set of values, not a scalar.
- It may be that systems can be *usefully* characterized by a small tuple.
  - <DGEMM, PTRANS, STREAM-TRIAD> ?

The Commercial Message

And check out
http://www.BigNComputing.org/

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Many of my other computers are

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